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THE DESIGN AND TESTING OF A LARGE PROPELLER DRIVEN AERATION DEVICE FOR RESERVOIR USE

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THE DESIGN AND TESTING OF A LARGE PROPELLER DRIVEN AERATION DEVICE FOR RESERVOIR USE

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ABSTRACT

A large propeller driven aeration device was designed and tested at Guelph Reservoir, Ontario, Canada. The unit consisted of a propeller driven by a submersible electric motor suspended in a 3 m diameter polystyrene tube. The tube extended 8 m below the lake's surface. The propeller had a rating of 2.9 $m^3 \cdot s^{-1}$, but was not powerful enough to destratify the reservoir. It is estimated that six more units would be required at the site in order to thoroughly mix the water column and prevent bottom water anoxia. The unit was able to draw water to the surface where it absorbed oxygen.

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Fig. 1. Scale diagram of the aeration unit. B, barrel for floatation; C, control panel; F, angle iron framework to suspend motor and tube; P, submersible motor with propeller; R, raft framework (6 m square); S, SOW electrical cable; T, polystyrene tube; TR, aluminum ring. Arrows indicate general direction of water movement.

Fig. 2. Electrical connections for the aeration unit.

Fig. 3. Currents measured off the east side of the raft (May 15, 1990). Arrow lengths scaled to current speed. Thin arrows from ≤1 cm/s to <4 cm/s; mid-size arrows from ≤4 cm/s to <10 cm/s; wide arrows ≤10 cm/s. Arrows point in direction of current flow from an overhead aspect.

Fig. 4. Surface temperature (°C) and dissolved oxygen (ppm) values. A, dissolved oxygen on June 13, 1990; B, Temperature on June 13, 1990; C, dissolved oxygen on August 14, 1990; D, Temperature on August 14, 1990. Westerly winds on both days; blank square in centre of each plot represents raft; solid squares represent sampling stations; scale bar equals 6 m.

Fig. 5 Dissolved oxygen profiles along west to east transects measured on August 14, 1990. A, detailed profile near the tube; B, longer transect indicating extent of mixing. Symbols as in Figure 4.

INTRODUCTION

The use of destratification to improve reservoir water quality and dissolved oxygen concentrations has had widespread application (Fast 1979; Burns and Powling, 1981; Pastorok et al., 1982; Pastorok and Grieb, 1984). The principle of operation is to thoroughly mix the water column by moving bottom water to the surface via air bubbles or some mechanical device (e.g. Johnson and Davis, 1980; Johnson, 1984). The desired result is oxygen saturation throughout the water column (primarily via gas exchange at the water surface), along with the water quality improvements that oxygen saturation implies, including:

(1) reduced internal phosphorus loading because of the oxic state of the sediments;
(2) rapid decomposition of accumulated organic matter on the bottom via oxidation (leading to a further reduction in BOD);
(3) precipitation of phosphorus out of the water column via its binding to iron hydroxides;
(4) the virtual elimination of hydrogen sulphide, ammonia and methane from the water column;
(5) the expansion of habitat for fish and zooplankton, which increases the potential for further water quality improvements via food chain manipulations (e.g. Theiss et al., 1990).

A desirable secondary effect of destratification is the reduction of surface blooms of blue-green algae (e.g. Steinberg, 1983). The effect may not be long lasting, however (Steinberg and Tille-Backhaus, 1990).

A propeller driven aeration unit was designed and tested in Guelph Reservoir, located just outside of Guelph, Ontario (43°36′N 80°15′W). The reservoir was a eutrophic, hardwater system designed for spring flood control. The reservoir had a surface area of 360 ha, mean depth of 4.5 m, maximum depth of 13 m, and normal operating volume of about 1.6×10^7 m^3. The hypolimnion lost oxygen after the onset of stratification each May and contained less than 0.5 ppm oxygen by mid June. The thermocline was weak with only a 4°C difference between surface and hypolimnetic waters by mid summer. The thermocline depth was 7 to 8 m. The hypolimnetic volume was approximately 1×10^6 m^3. Hypolimnetic anoxia lasted until the end of each September, when the fall overturn abruptly increased the oxygen content of the bottom waters.

THE AERATION UNIT DESIGN

The aeration unit was a relatively simple device consisting of a square (6 m by 6 m) raft which suspended a tube housing an electrically powered propeller (Figure 1). The raft was constructed of 0.5 cm thick, 3.8 cm by 3.8 cm welded angle iron and floated with three 230 L steel drums at each corner. The tube was made of 2 mm thick extruded polystyrene sheets attached to 14 cm wide (3 mm thick) aluminum rings by large headed sheet metal screws. The tube extended 8 m down into the lake.

The propeller was a Model 4410 electric submersible mixer manufactured by Flygt[*] (Flygt Canada, Etobicoke, Ontario) for use in water treatment plants. The propeller was 2.2 m in diameter and consisted of two "banana" style blades powered by a 3.2 hp, 600 Volt, three phase submersible electric motor attached directly to the blades via a reduction gearbox. The propeller speed was 32.3 RPM and it was designed to move water at a rate of 2.9 $m^3 \cdot s^{-1}$. A #14 size four conductor (line to neutral) neoprene jacketed cabtire cable (SOW cable) attached the motor to a control panel (starter and disconnect) mounted on the raft.

A 500 m long #10 size four conductor SOW cable laid along the reservoir bottom from the raft control panel into the powerhouse of the Guelph Reservoir dam provided electricity. A very sensitive ground fault interrupter was designed by Federal Pioneer Ltd. (Toronto, Ontario), with an adjustable ground sensing relay. The relay was installed in the dam to shut of power to the SOW cables if any short circuits were detected in the system.

The relay was set to a sensitivity of 30 mA with a one second response time. Figure 2 summarizes the electrical connections involved.

The raft was anchored by four 9.4 cm diameter steel cables attached to augers screwed into the lake bottom by divers. The aeration unit was tested in the lake during September, 1988 and appeared to be mechanically sound. The unit was later placed in the deepest part (13 m) of Guelph reservoir near the dam for routine continuous operation and periodic testing during two ice free seasons, June to November in 1989 and April to November in 1990. The unit was dismantled for winter storage each year.

TESTING THE UNIT

A Neil Brown smart current meter (self reading; E.G.& G. Ltd., Mass.) was used to sample currents along a transect off the eastern side of the raft on May 15, 1990. The flowmeter was passed down through the water column at stations 2, 5 and 10 m distant from the raft. The results are presented in Figure 3. The propeller created a complex series of currents and counter currents which tended to spiral around the raft. The strongest currents (26 cm/s) were found close to the raft (2 m away) at the surface and flowed outwards in a north easterly direction. Counter currents in the opposite direction at 1 m and 2 m depths moved water back towards the raft in an eddy. Relatively weak (2 to 5 cm/s) currents at 8 and 9 m depths moved water towards the intake of the raft tube (i.e. towards the west).

On June 13, 1990 and August 14, 1990, dissolved oxygen and temperature readings were taken at a variety of stations around the raft with a Y.S.I. model 58 dissolved oxygen and temperature meter which had been calibrated in a laboratory just prior to sampling. Oxygen measurements were verified with the azide modification of the Winkler titration technique (APHA et al., 1976). Meter oxygen readings were typically ±10% of the titration values for any one profile. The data were analyzed by a contour plotting program which utilized a Kriging algorithm. Figure 4 provides a summary of the surface plotting results. On June 13, water at 8 and 9 m (tube intake depth) had 4 ppm dissolved oxygen and a temperature of 16°C. Figure 4 A and B illustrate how the aeration unit brought this intake depth water to the surface. Both surface water temperature and dissolved oxygen increased with distance away from the raft. Dissolved oxygen values at the surface (Figure 4A) were probably not as low as expected (4 ppm right at the raft) due to oxygen uptake at the surface which would be enhanced by the near surface eddy currents described above.

On August 14, water at 8 and 9 m depth had less than 0.4 ppm dissolved oxygen and a temperature of 21°C. Figures 4 C and D reaffirm that the intake depth water was moved to the surface by the aeration unit. Note that the temperature difference between intake depth and surface waters near the raft on both dates was approximately 1°C and the difference in dissolved oxygen content was approximately 4 ppm. The aeration unit acted to bring intake level water to the surface where it absorbed oxygen.

Data from the August 14, 1990 sampling were plotted as a west to east dissolved oxygen profile in Figure 5A. A longer west to east transect was sampled on the same day and the results plotted as Figure 5B. Figure 5 indicates that the aeration unit was not able to destroy the lake's oxygen stratification, although it certainly distorted the stratification near the unit. The profiles also show how water with lower dissolved oxygen was being drawn upwards, probably by a combination of the movement of water in the tube itself and complex eddy currents outside of the tube.

CONCLUSION

The aeration unit was capable of drawing low dissolved oxygen water towards the surface where it was aerated. The unit was not capable of destratifying the reservoir. Since the aeration unit had a maximum potential of 2.9 $m^3 \cdot s^{-1}$ (propeller rating) and the Guelph Reservoir volume was approximately 1.6 X 10^7 m^3, it would have taken 61 days to mix the entire reservoir volume with the single unit.

Destratification with good dissolved oxygen concentrations in bottom waters (over 4 ppm) during summer months may require mixing the entire Guelph Reservoir volume within an eight day cycle (Vandermeulen, unpublished results). An additional six aeration units would be required at the site in order to move the volume within that time frame.

ACKNOWLEDGEMENTS

Thanks are due to Kenneth Ashley of The British Columbia Ministry of the Environment (Vancouver) for suggesting the concept of a propeller with a submersible electric motor for reservoir aeration. Assembly and installation of the aeration unit was performed by Al Melkic and the crew at Integrated Explorations (Guelph, Ontario). Andy Gemza (Water Resources Branch, Ontario Ministry of the Environment) carried out the field sampling and Don McQueen (York University, Biology Department) provided the current meter and assisted with its use in the field.

REFERENCES

American Public Health Association, American Water Works Association and Water Pollution Control Federation (1976) Standard methods for the examination of water and wastewater. 14th ed. American Public Health Association. Washington, D.C. 1193 pp.

Burns F.L. and Powling I.J. (1981) Destratification of lakes and reservoirs to improve water quality. Australian Water Resources Council, Canberra. 915 pp.

Fast A.W. (1979) Artificial aeration as a lake restoration technique. In Proc. Nat. Conf. on Lake Restoration. pp. 121-131. U.S. EPA Washington, D.C.

Johnson D. and Davis J.M. (1980) Reservoir mixing techniques: Recent experience in the UK. In Proc. Int. Symp. on Inland Waters and Lake Restoration. pp. 140-145. U.S. EPA Washington, D.C.

Johnson P.L. (1984) Thoughts on selection and design of reservoir aeration devices. In Proc. 3rd NALMS Conf., pp. 537-541. U.S. EPA Washington, D.C.

Pastorok R.A. and Grieb T.M. (1984) Prediction of lake response to induced circulation. In Proc. 3rd NALMS Conf., pp. 531-536. U.S. EPA Washington, D.C.

Pastorok R.A., Lorenzen M.W. and Ginn T.C. (1982) Artificial aeration and oxygenation of reservoirs: A review of theory, techniques and experiences. Tech. Rep. E-82-3, U.S. Army Corps Eng., Waterways Exp. Sta., Vicksburg, Miss. 192 pp.

Steinberg C. (1983) Effects of artificial destratification on the phytoplankton populations in a small lake. J. Plankton Res. **5**, 855-864.

Steinberg C. and Tille-Backhaus R. (1990) Re-occurrence of filamentous planktonic cyanobacteria during permanent artificial destratification. J. Plankton Res. **12**, 661-664.

Theiss J., Zielinski K. and Lang H. (1990) Biomanipulation by introduction of herbivorous zooplankton. A helpful shock for eutrophic lakes? Hydrobiologia **200/201**, 59-68.

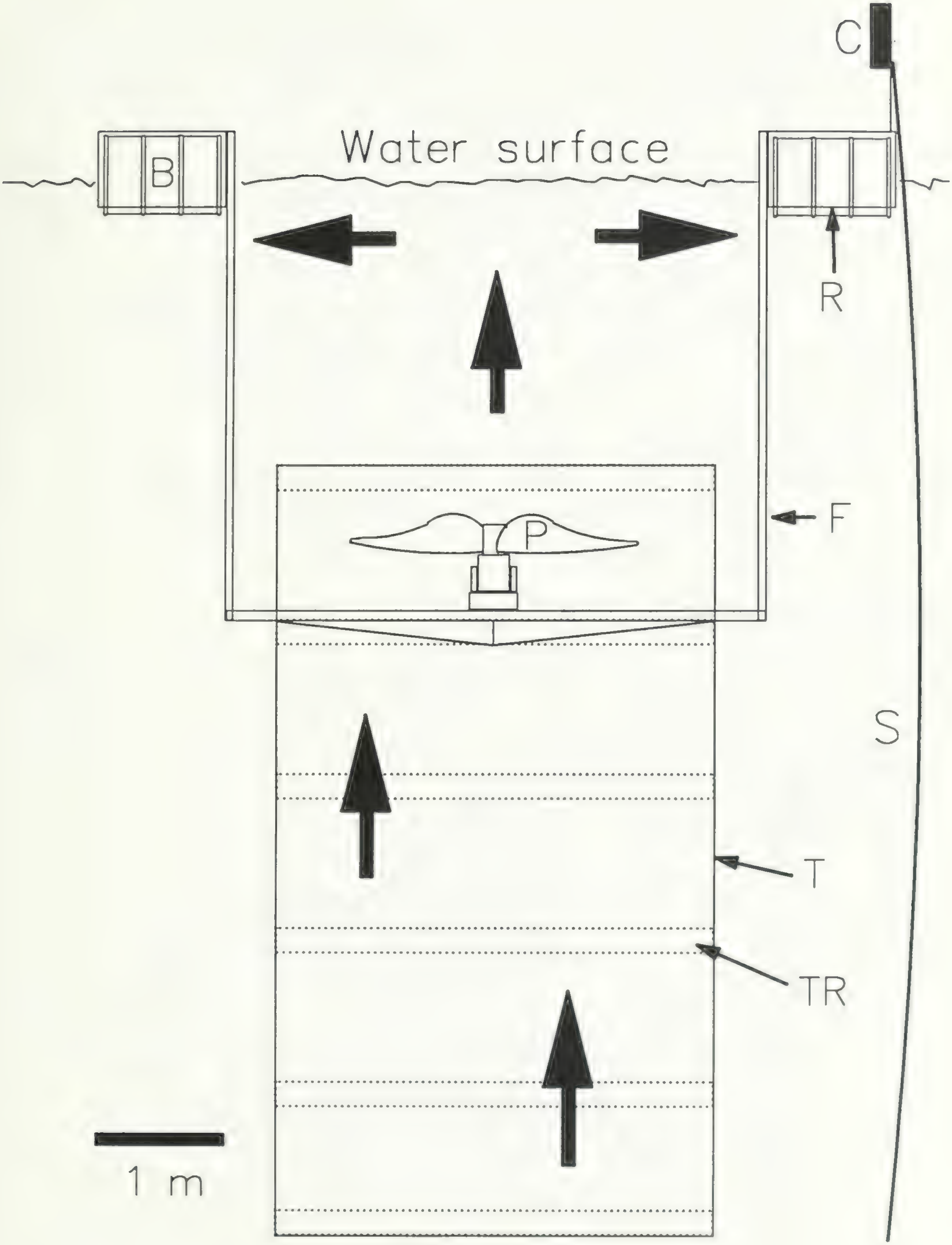
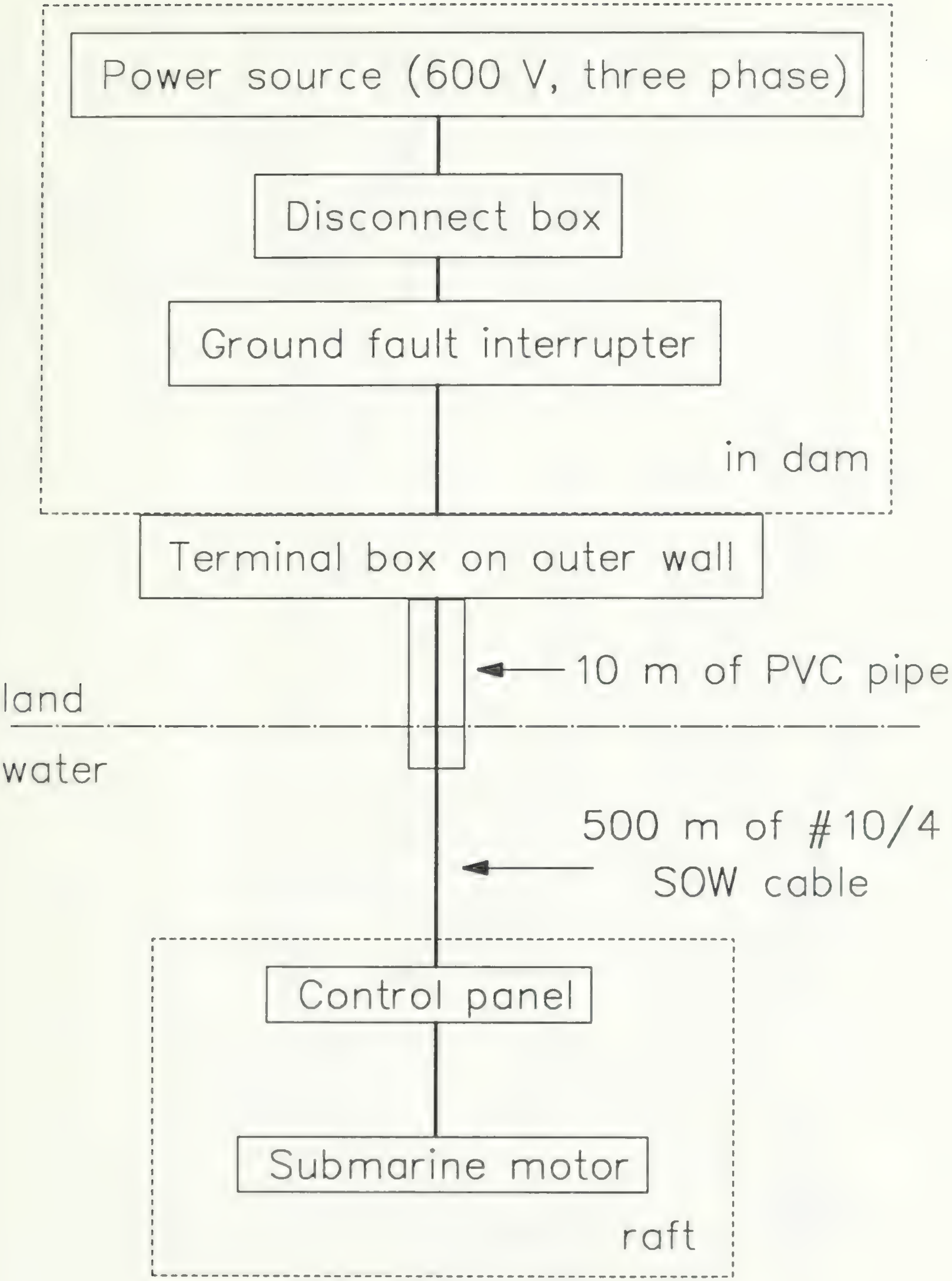


Fig. 1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Ground fault interrupter
in dam
Terminal box on outer wall
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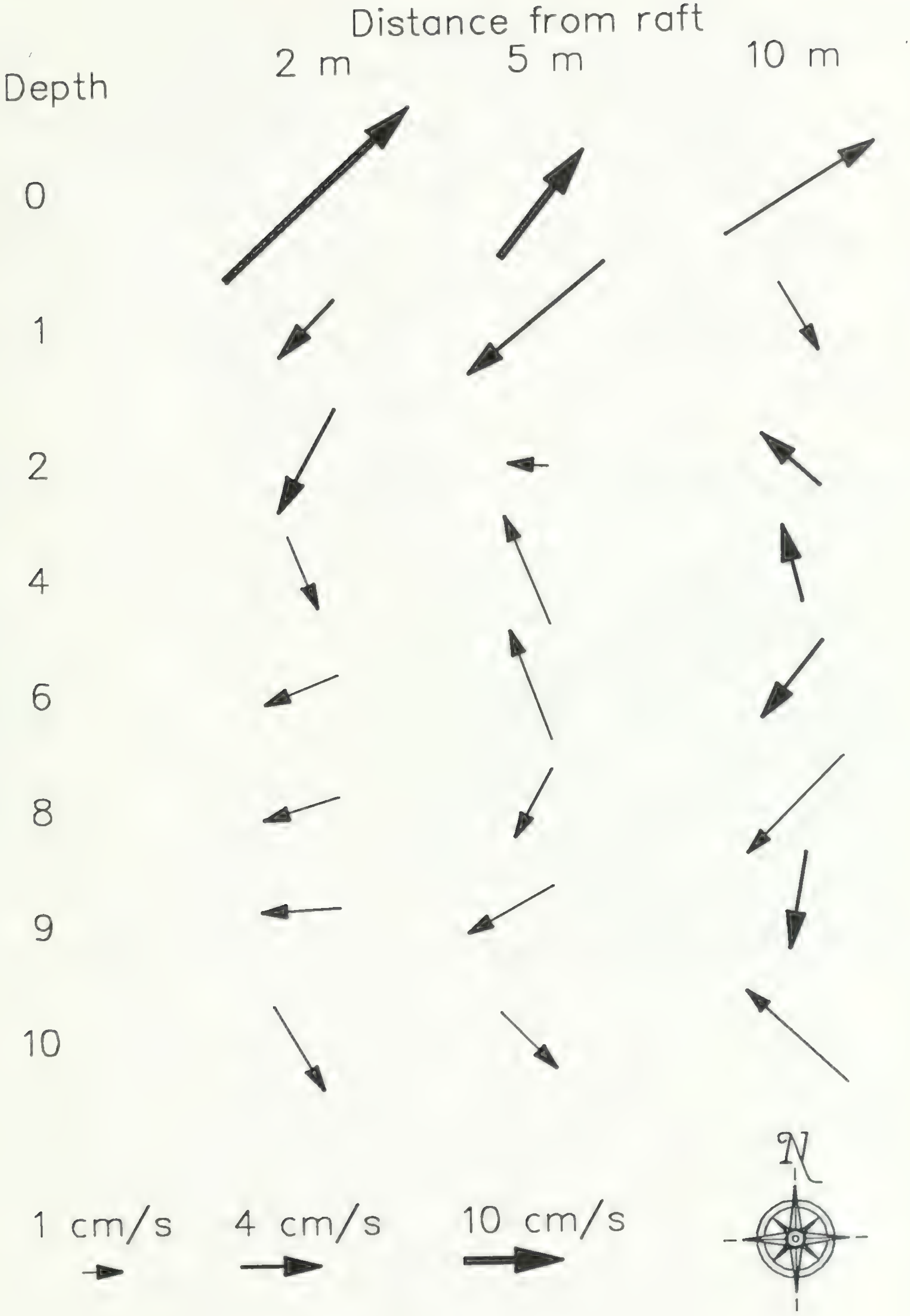
land
water
500 m of #10/4 SOW cable
Control panel
Submarine motor
raft

Fig. 2


Distance from raft
2 m
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10 m
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2
4
6
8
9
10
1 cm/s
4 cm/s
10 cm/s
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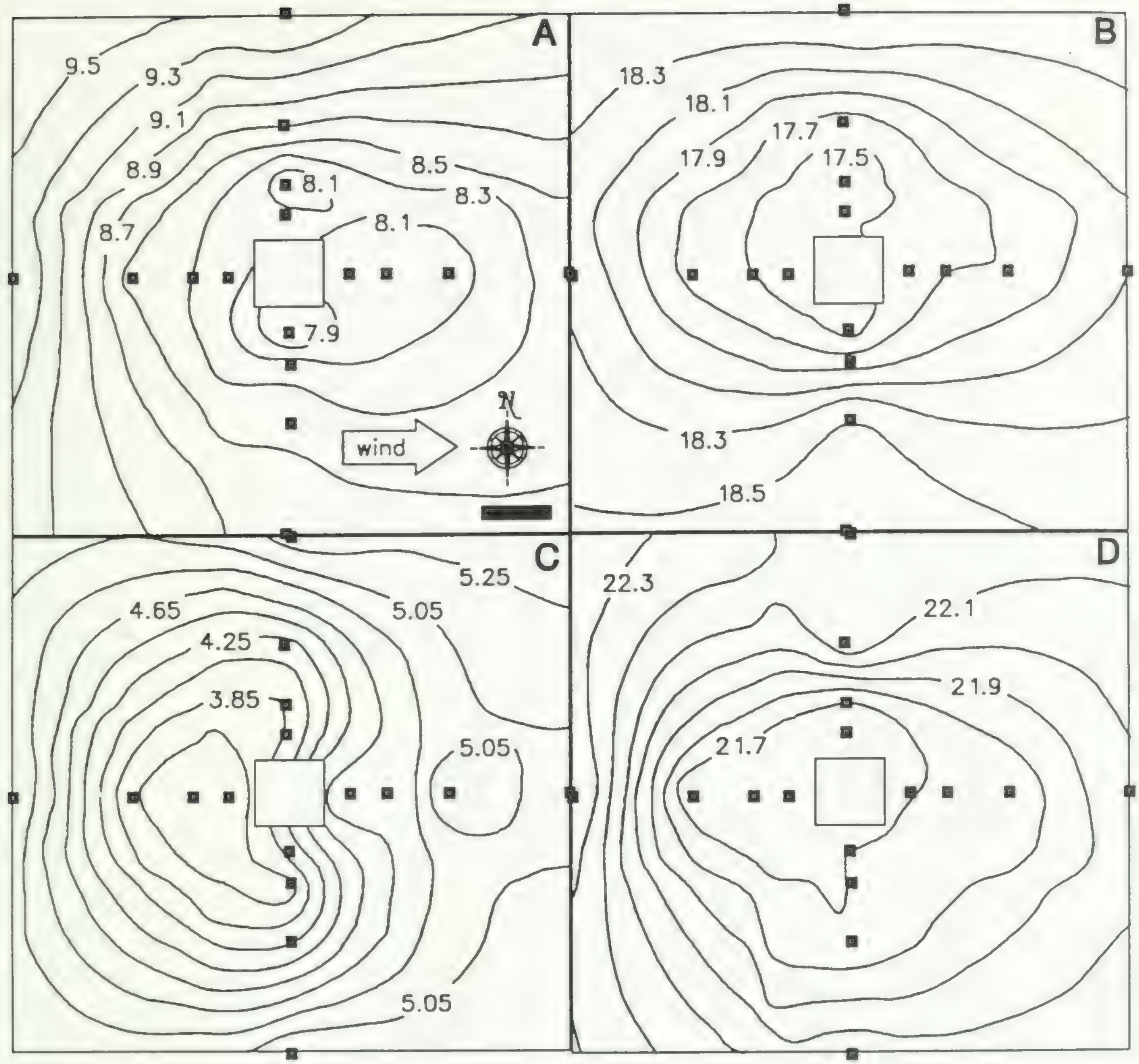
Fig. 3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9.1
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18.1
17.7
17.9
17.5
18.3
18.5
C
5.25
4.65
5.05
4.25
3.85
5.05
5.05
D
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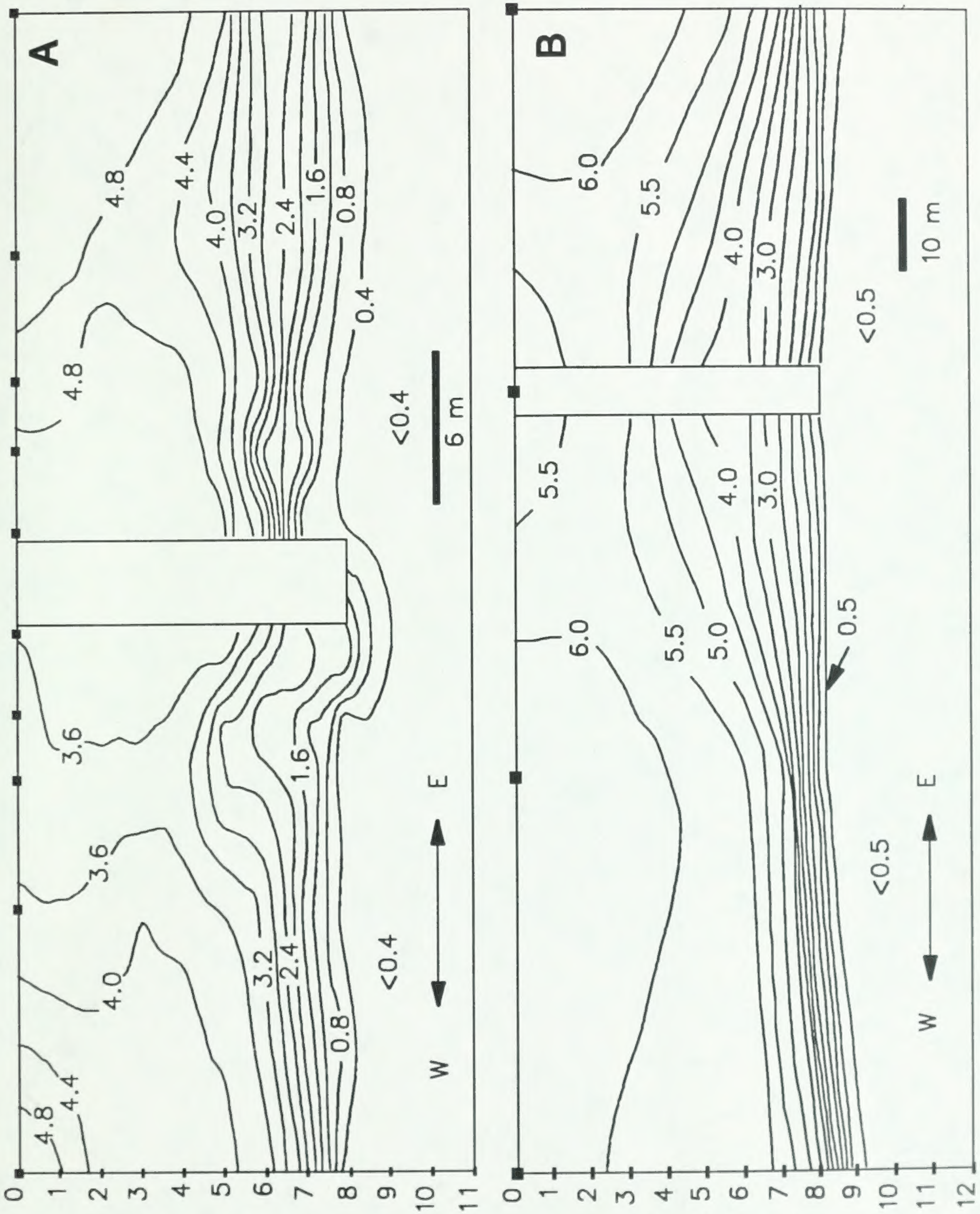
22.1
21.9
21.7

Fig. 4


A
B
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3
4
5
6
7
8
9
10
11
12
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4.4
4.0
3.6
3.2
2.4
1.6
0.8
0.4
<0.4
6 m
W
E
6.0
5.5
5.0
4.0
3.0
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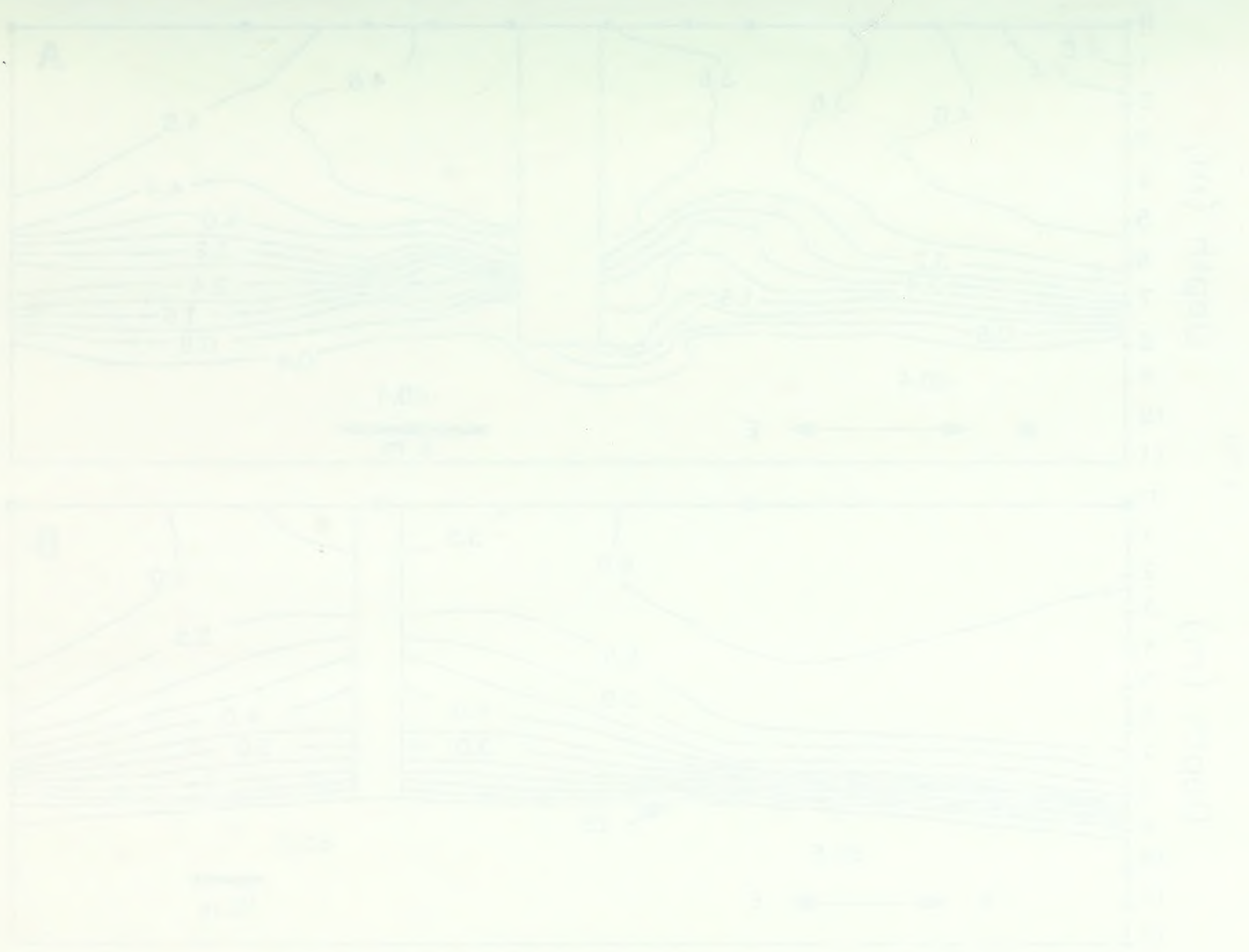
<0.5
10 m

Fig. 5


A
B